Name: ______________________________

GTID: ______________________________

ECE 6390: Satellite Communications and Navigation Systems
TEST 1 (Fall 2007)

- Please read all instructions before continuing with the test.
- This is a **closed** notes, **closed** book, **closed** friend, **open** mind test. On your desk you should only have writing instruments and a calculator.
- Show all work. (It helps me to give partial credit.) Work all problems in the spaces below the problem statement. If you need more room, use the back of the page. DO NOT use or attach extra sheets of paper for work.
- Work intelligently – read through the exam and do the easiest problems first. Save the hard ones for last.
- All necessary mathematical formulas are included either in the problem statements or the last page of this test.
- You have 80 minutes to complete this examination. When the proctor announces a "last call" for examination papers, he will leave the room in 5 minutes. The fact that the proctor does not have your examination in hand will not stop him.
- I will not grade your examination if you fail to 1) put your name and GTID number in the upper left-hand blanks on this page or 2) sign the blank below acknowledging the terms of this test and the honor code policy.
- Have a nice day!

Pledge Signature: ____

I acknowledge the above terms for taking this examination. I have neither given nor received unauthorized help on this test. I have followed the Georgia Tech honor code in preparing and submitting the test.

1. **Short Answer Section** (**10 points**)

   (a) ______________ (1) ______________ (2) ______________ (3) ______________ (4)
   List four types of electric power sources used on satellites.

   (b) __________________
   The name of the first man-made satellite was $\boxed{\textit{Answer}}$.

2. **Plane Wave Equations:** (**30 points**)

   You measure the time-harmonic electric field around an earth station to be:

   $$\tilde{\vec{E}}(\vec{r}) = 10[\hat{x} + \hat{y}]\exp\left(-j\,[\hat{x} - \hat{y} - \hat{z}] \cdot \vec{r}\right) \text{ mV/m (in free space)}$$

   Answer the following questions based on this measured field value:

   (a) What is the equation for the magnetic field of this plane wave? (**10 points**)

   (b) What is the frequency of this electromagnetic wave? (**10 points**)

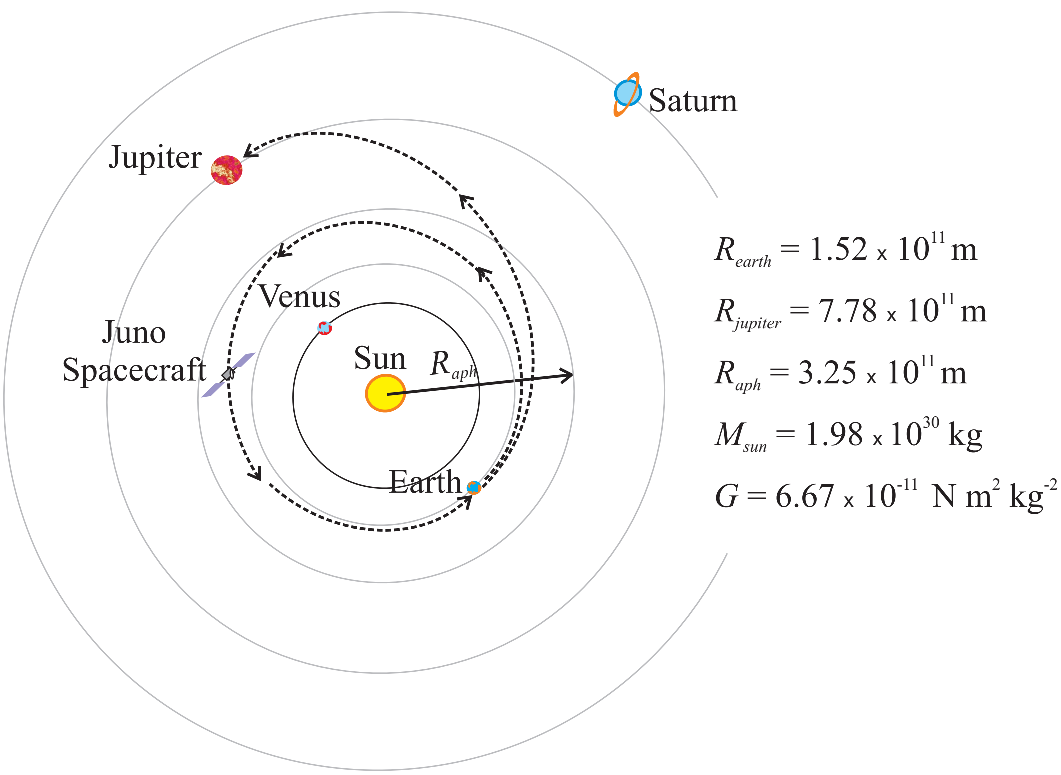
   (c) If the xy-plane corresponds to the earth's surface (this means locally $+\hat{y}$ points North, $+\hat{x}$ points East, and $+\hat{z}$ points straight overhead), then what azimuth and elevation angle must we point a dish antenna to receive this wave? Use the cartography/radio wave conventions where azimuth is measured clockwise from North and elevation is measured from the horizon. Make sure answers are in degrees. (**10 points**)

3. **Deep Space Orbits:** A "gravitational slingshot" is a method for propelling a spacecraft to outer planets without using extraordinary amounts of fuel, cost, and propulsion complexity. Under most circumstances, the orbit of a satellite around the solar system is an ellipse with the massive sun at one of the focii. The sun provides the principle gravitational forces to maintain the orbit, unless the spacecraft approaches very close to a planet. For a brief time period, the spacecraft can get a "free" boost in its relative velocity with respect to the sun by getting "slung forward" by the nearby gravity well of a planet in motion. This will transfer the satellite to a higher orbit without firing thrusters. Conservation of energy still holds – the spacecraft is simply borrowing some of the momentum of the massive, moving planet.

   Below is a series of approximate proposed slingshot and orbits for use in NASA's Juno mission to Jupiter, with a proposed launch in August 2011. The spacecraft will first travel a full elliptical orbit with aphelion of $R_{aph} = 3.25 \times 10^{11}$m back to Earth to receive its slingshot. After this boost, the spacecraft completes a half-orbit that will rendezvous with Jupiter. Clearly, this is a very effective albeit time-consuming method for traveling to distant planets.

   Below is a diagram of Juno's approximate path through the solar system, as well as all the pertinent planetary data. Estimate the year and month that the spacecraft first arrived at Jupiter. Show *all* the steps in your calculation, using the back of this page if necessary. (**30 points**) (**25 points**)

   Why was this particular R_{aph} chosen for the first orbital sequence? (**5 points**)



4. **Link Budget for Neptunian Probe:** The planet Neptune is 4.45×10^9 km from Earth at the time a NASA space probe must communicate back to an earth station using a 28 GHz carrier with a minimum received power of -110 dBm. Based on this scenario, answer the following questions. (**30 points**)

   (a) If the Earth station's receiver dish gain were 70 dBi and the satellite's antenna dish were 50 dBi, what is the minimum transmit amplifier output in Watts at the satellite? (**8 points**)

   (b) If the transmit amplifier's maximum output is 500 W and the Earth station's receiver dish antenna must be 10 times larger in electromagnetic area than the transmitter antenna (implying 10 dB greater antenna gain), at least how much gain must the satellite dish antenna have? (**10 points**)

   (c) Discounting costs, what are 2 drawbacks for increasing transmitter antenna gain on the satellite? (**8 points**)

   (d) Discounting costs, what is one drawback when installing a higher-powered transmit amplifier on the satellite? (**4 points**)

Cheat Sheet

$\lambda f = c \qquad c = 3 \times 10^8$ m/s $\qquad \epsilon_o = 8.85 \times 10^{-12}$ F/m $\qquad \mu_o = 4\pi \times 10^{-7}$ H/m $\qquad k = \dfrac{2\pi}{\lambda}$

$$\begin{aligned}
\tilde{\vec{\mathsf{E}}}(\vec{\mathrm{r}}) &= E_0 \hat{\mathrm{e}} \exp(j[\phi - k\hat{\mathrm{k}} \cdot \vec{\mathrm{r}}]) \\
\tilde{\vec{\mathsf{H}}}(\vec{\mathrm{r}}) &= H_0 \hat{\mathrm{h}} \exp(j[\phi - k\hat{\mathrm{k}} \cdot \vec{\mathrm{r}}])
\end{aligned}$$

$$H_0 = \frac{E_0}{\eta} \qquad \eta = \sqrt{\frac{\mu}{\epsilon}} \qquad v_p = \frac{1}{\sqrt{\mu\epsilon}} \qquad \hat{\mathrm{e}} \times \hat{\mathrm{h}}^* = \hat{\mathrm{k}} \qquad \hat{\mathrm{h}} = (\hat{\mathrm{k}} \times \hat{\mathrm{e}})^*$$

$$\ddot{r} = r\dot{\theta}^2 - \frac{GM_P}{r^2} \qquad \ddot{\theta} = -\frac{2\dot{r}\dot{\theta}}{r}$$

$$T^2 = \frac{4\pi^2 a^3}{\mu} \qquad \mu = GM_p \qquad G = 6.672 \times 10^{-11}\ \mathrm{Nm^2/kg^2} \qquad M_E = 5.974 \times 10^{24}\ \mathrm{kg}$$

$$b = a\sqrt{1 - e^2} \qquad \text{perigee} = (1-e)a \qquad \text{apogee} = (1+e)a$$

Circular Orbit: $V = \sqrt{\dfrac{\mu}{R}}$

Logarithmic Link Budget: $P_R = P_T + G_T + G_R - 20\log_{10}\left(\dfrac{4\pi}{\lambda}\right) - 20\log_{10}(r)$

Cross Product: $\vec{\mathrm{a}} \times \vec{\mathrm{b}} = \det \begin{vmatrix} \hat{\mathrm{x}} & \hat{\mathrm{y}} & \hat{\mathrm{z}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$

Angle-of-Arrival (CAREFUL: elevation measured from z-axis in this formula)

$$-\hat{\mathrm{k}} = \cos\varphi \sin\theta\, \hat{\mathrm{x}} + \sin\varphi \sin\theta\, \hat{\mathrm{y}} + \cos\theta\, \hat{\mathrm{z}}$$

$$\theta = \cos^{-1} -k_z \qquad \varphi = \tan^{-1}\frac{k_y}{k_x} \quad (\text{add } \pi \text{ if } k_x > 0)$$